

Ecosystem change and land-surface-cloud coupling

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Outline of Talk

- **Land-surface climate:**

- **surface & cloud processes**

- 1) LBA data: Jaru forest & Rondonia pasture

- 2) Idealized equilibrium model:

- forest and grassland; double CO₂

- impact on BL cloud, NEE and temperature

Land surface climate

- **Highly coupled system: mean state + diurnal cycle**
 - **Surface processes:** evaporation & carbon exchange
 - **Atmospheric processes:** clouds & precipitation
- **Clouds have radiative impact on SEB in both shortwave and longwave**
- **Precipitation affects RH and LCL**
- **Clouds are “observable”, but are poorly modeled**
- **Quantify by scaling shortwave cloud forcing as an “effective cloud albedo”**

“Cloud Albedo”

$$SW_{\text{net}} = SW_{\text{down}} - SW_{\text{up}} = (1 - \alpha_{\text{surf}})(1 - \alpha_{\text{cloud}}) SW_{\text{down}}(\text{clear})$$

- *surface albedo*

$$\alpha_{\text{surf}} = SW_{\text{up}} / SW_{\text{down}}$$

- *effective cloud albedo*

- a **scaled surface short-wave cloud forcing, SWCF**

$$\alpha_{\text{cloud}} = - SWCF / SW_{\text{down}}(\text{clear})$$

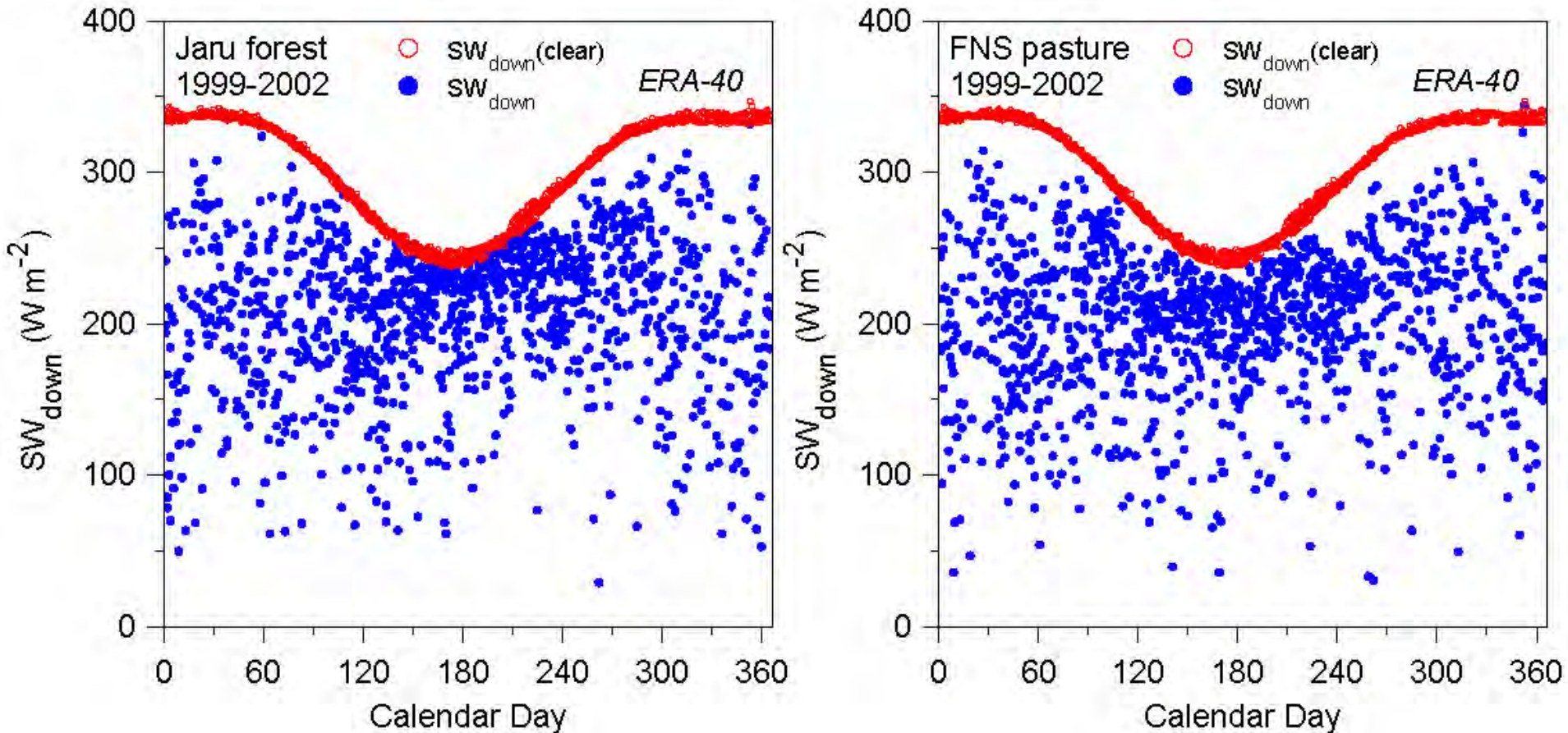
where

$$SWCF = SW_{\text{down}} - SW_{\text{down}}(\text{clear})$$

[Betts and Viterbo, 2005; Betts, 2007]

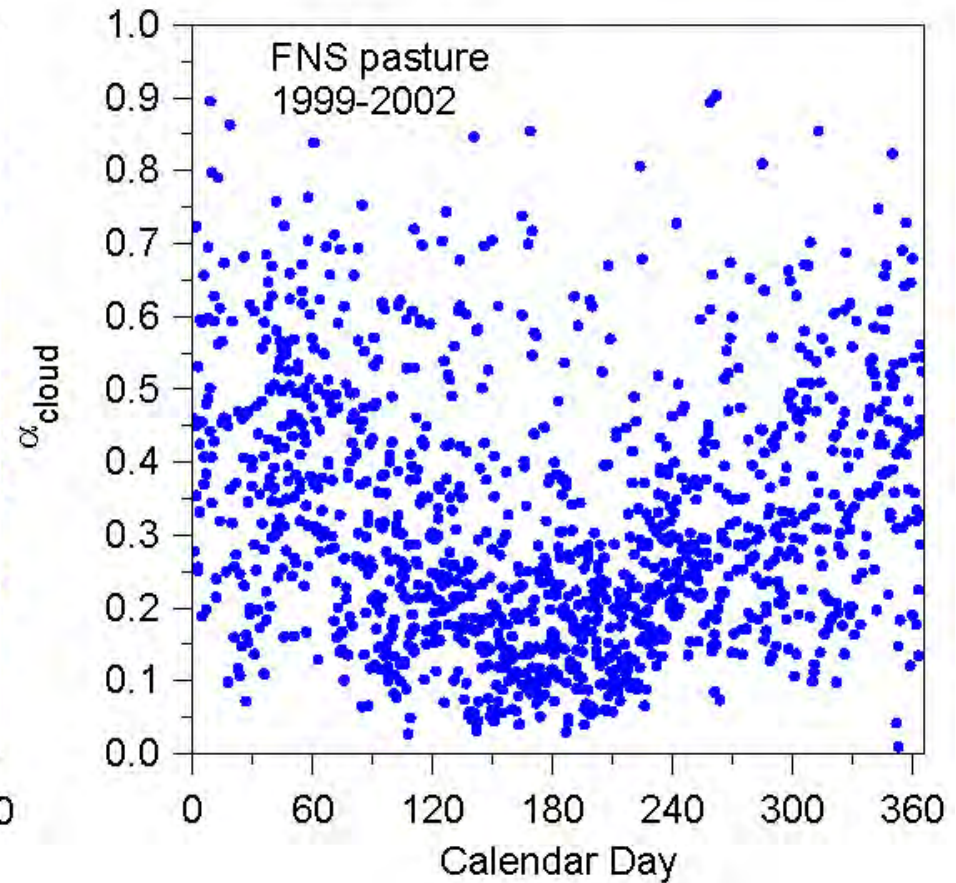
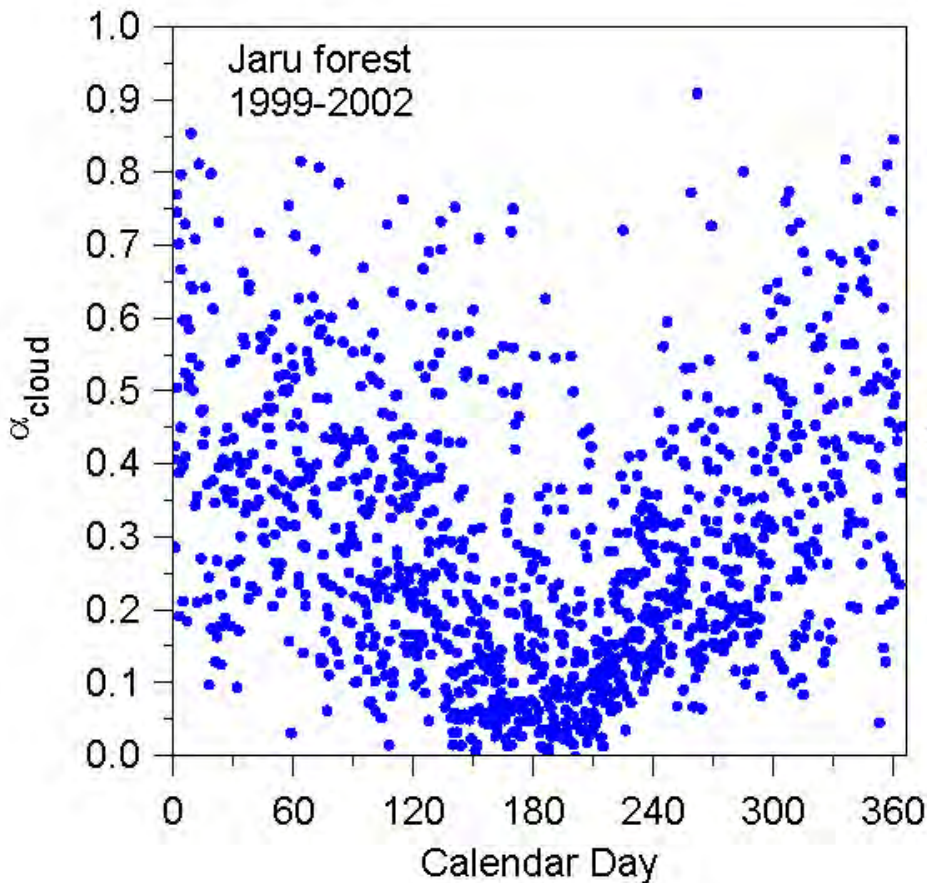
Jaru forest & Rondonia pasture : SWCF

[daily mean data: von Randow et al 2004]



- More cloud over pasture in dry season
- Aerosol 'gap' in September burning season

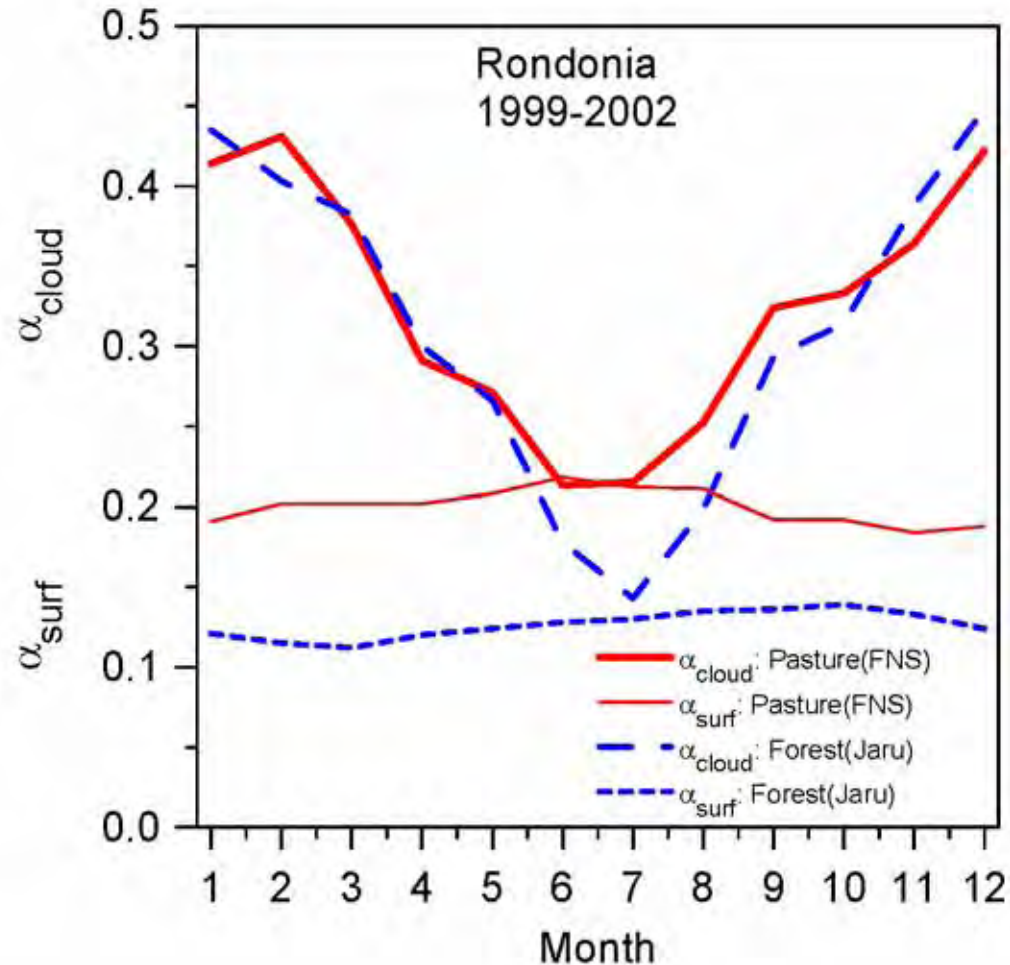
Jaru forest & Rondonia pasture transformation to α_{cloud}



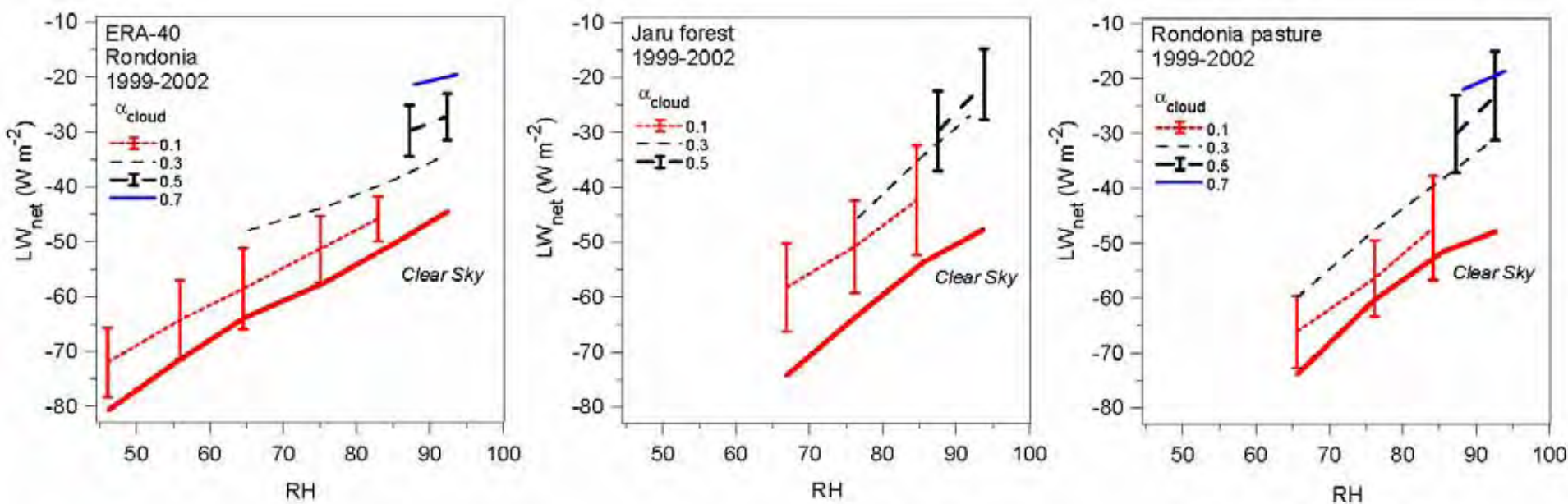
- More cloud over pasture in dry season

SW energy balance: forest and pasture

- Pasture in July, has
 - +8% surface albedo
 - +7% cloud albedo



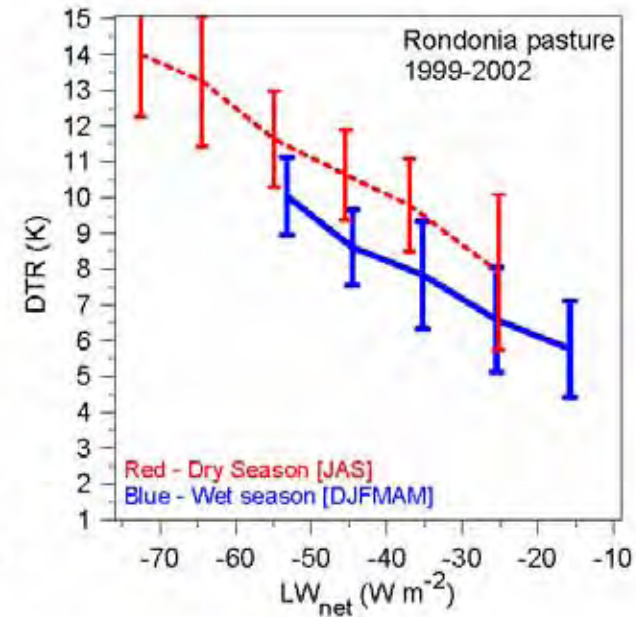
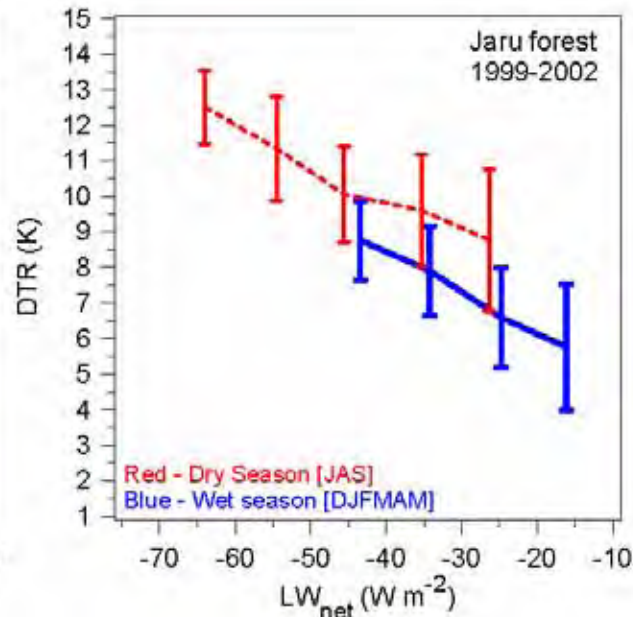
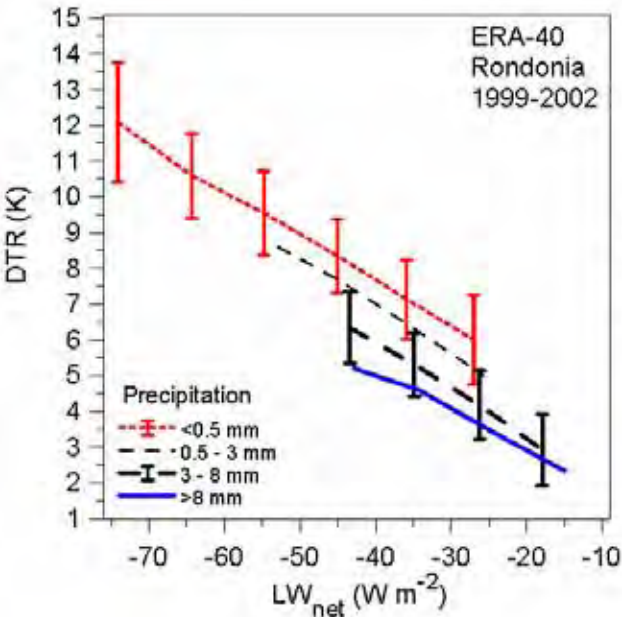
RH & cloud \rightarrow LW_{net}



- ERA40 “point”; Jaru tower & Rondonia pasture
- Broadly similar [ERA-40 has ‘drier’ data]
- Humidity and cloud greenhouse effects

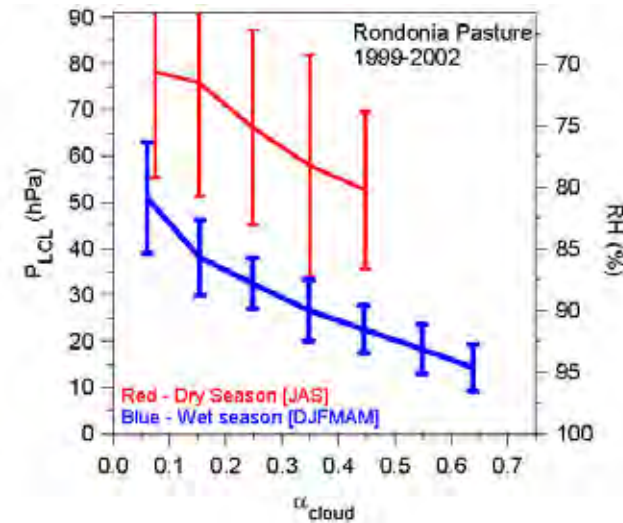
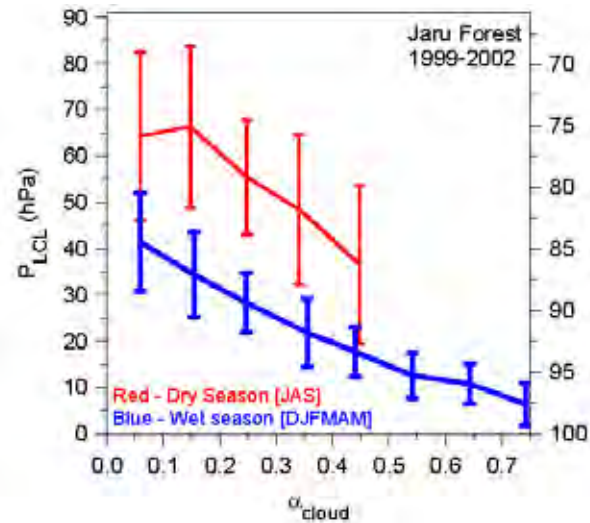
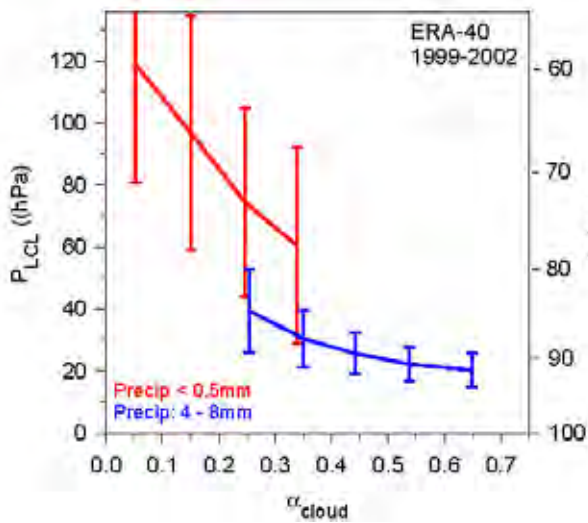
[ERA-40 calculations for clear sky]

$LW_{net} \rightarrow$ Diurnal Temp. Range



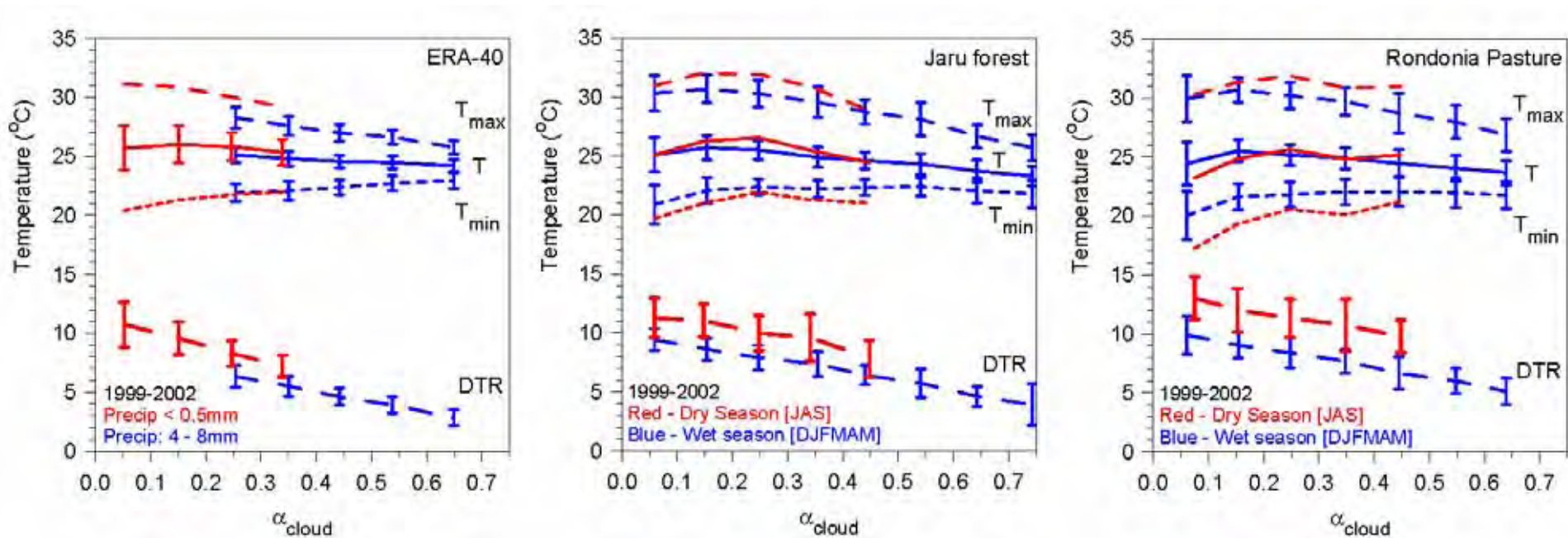
- **DTR quasi-linear with LW_{net}**
- ERA40 has steeper slope than observations
- Precipitation reduces DTR

Organize by α_{cloud} [*observable*]



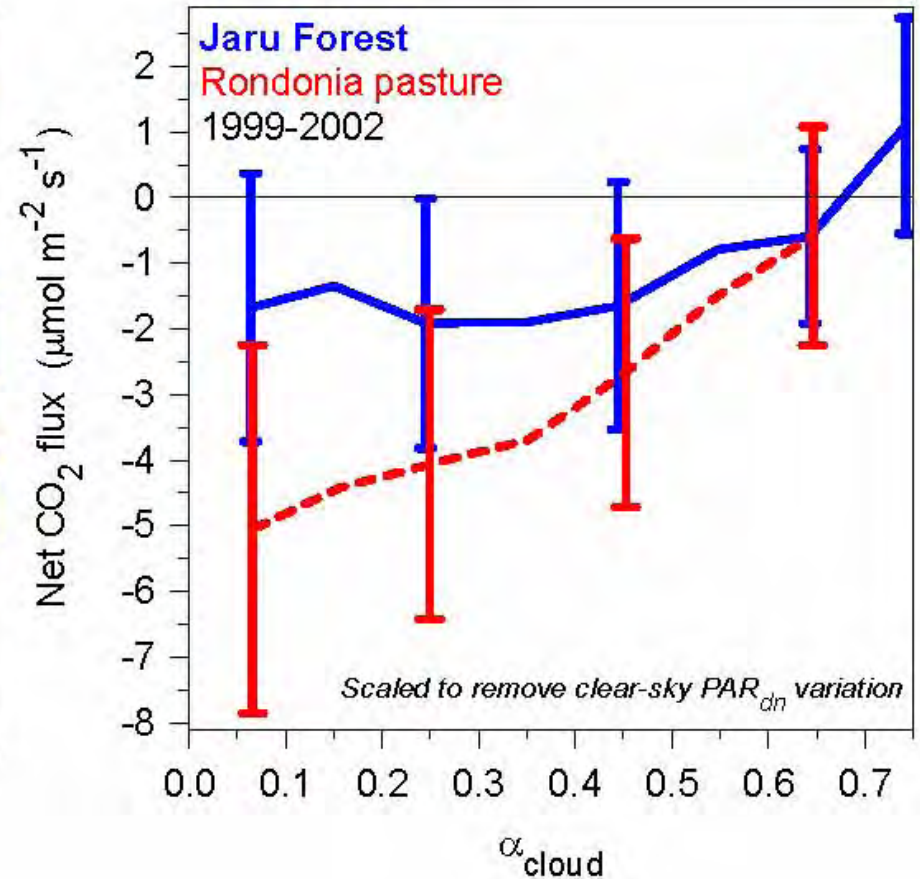
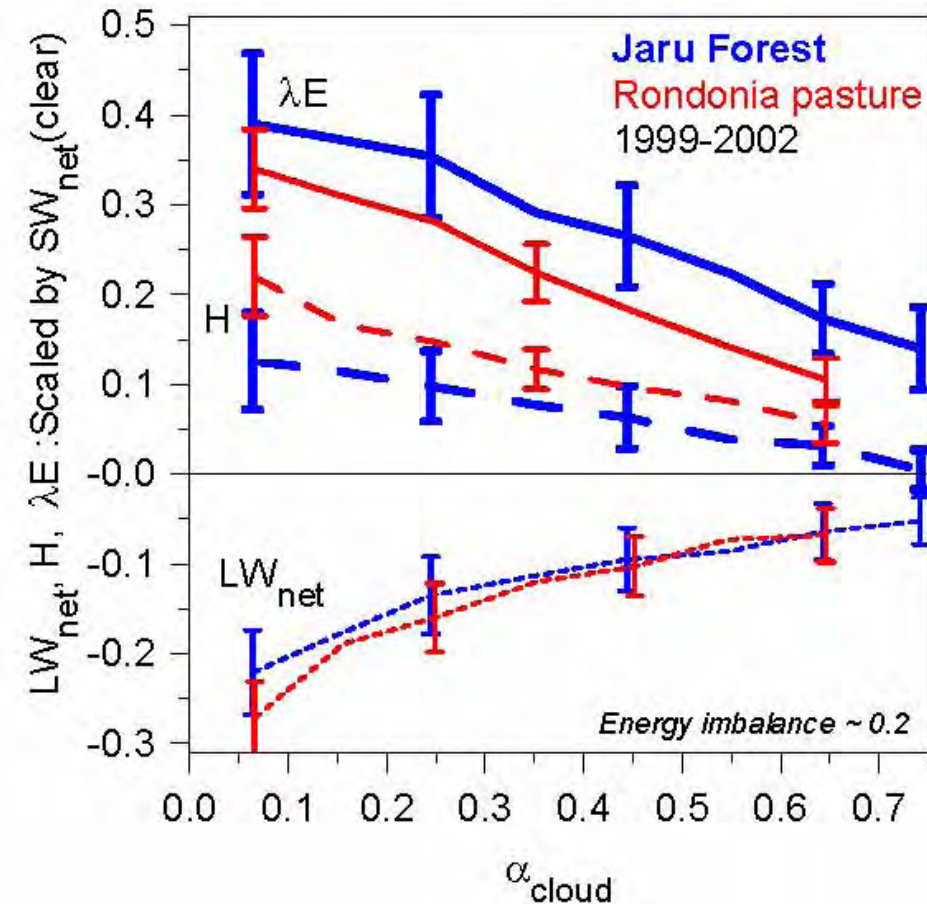
- α_{cloud} , LCL & RH linked
- Relation tight in rainy season;
- poor in dry season

T_{\max} , T_{\min} , DTR and α_{cloud}



- **DTR and α_{cloud} linked**
- ERA-40: T_{\max} decreases & T_{\min} increases
- Data: Wet season: T_{\max} decreases: T_{\min} flat

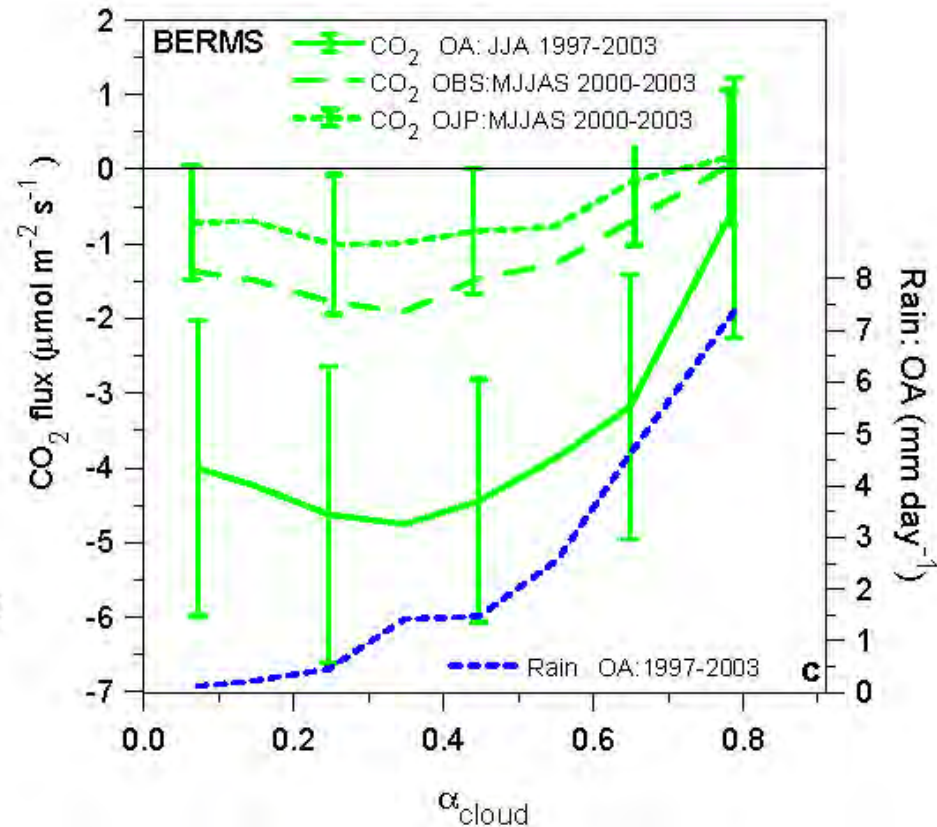
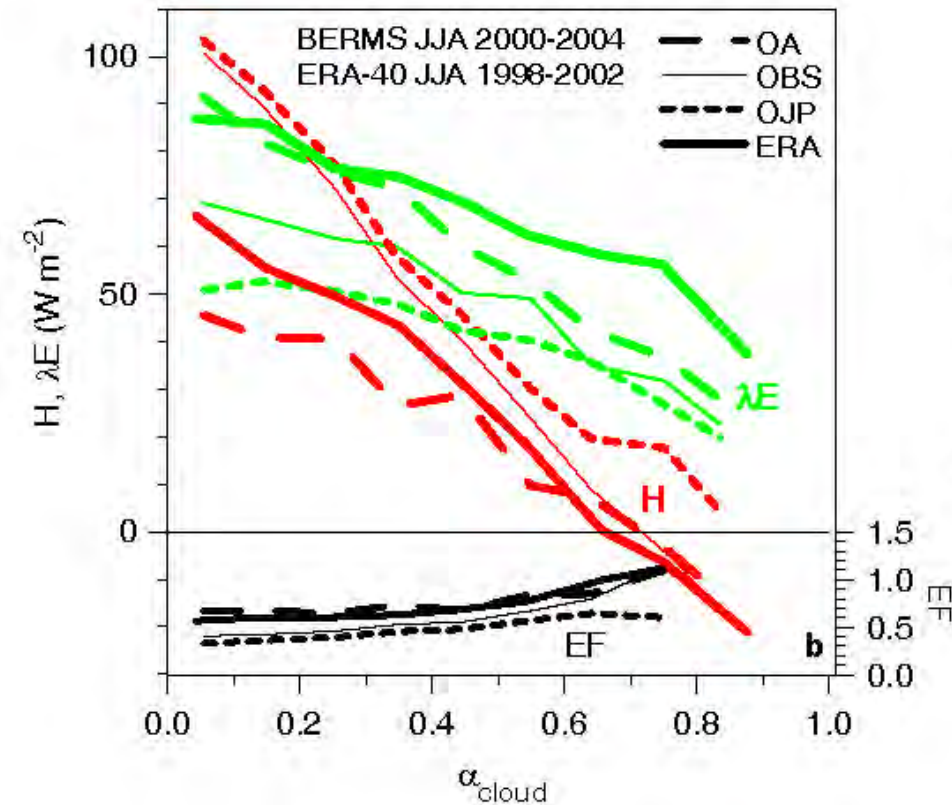
Organize fluxes by α_{cloud}



- Energy fluxes: quasi-linear
- Jaru forest carbon flux 'flat' at low α_{cloud}

Summer Boreal forest: Saskatchewan

[Betts et al. 2006]



- Similar dependency on α_{cloud}
- Net CO₂ flux peaks at $\alpha_{cloud} \sim 0.35$

2) How will BL clouds and surface fluxes change in a warmer, high CO₂ world?

- Global and continental climate needs fully coupled system
- But vegetation-CO₂-λE-BL-cloud coupling may have significant errors
- Use **idealized model** to study coupled BL system as a function of soil water with specified mid-tropospheric forcing
 - with SWCF and LWCF for BL clouds

Idealized Equilibrium BL model

- extension of

Betts, A. K., B. Helliker and J. Berry, 2004, Coupling between CO₂, water vapor, temperature and radon and their fluxes in an idealized equilibrium boundary layer over land. J. Geophys. Res., 109, D18103, doi:10.1029/2003JD004420.

- Heat, radiation, moisture and CO₂ balanced ML-model with BL cloud forcing only

Model Structure

- External variables: **soil moisture index**; mid-tropospheric CO_2 , RH, lapse-rate [coupled to moist adiabat]; Clear-sky SW_{net} radiation
- SW_{net} , LW_{net} , R_{net} and ML cooling coupled to cloud-base mass flux [‘cloud forcing’]
- Canopy photosynthesis model: [Collatz et al, 1991]
[LAI, E_{veg} , Q_{10}] = [5, 6, 1.9] for **forest** [Wisconsin]
= [3, 10, 2.1] for **grassland**
 - Temperature and soil water stress factors

Schematic

RH_t, CO_{2t}, θ_t specified

$P_{sf} - 350$: CBL top specified

Cloud-layer

Constant subsidence: $\rho_b W_{Eb}$

$P_{LCLcld} : RH_{cld}, q_{cld}, \theta_{cld}, CO_{2cld}$

$P_{sf} - P_{LCL}$: cloud-base pressure

Entrainment fluxes linked to jumps and $\rho_b(W_{Eb} + W_{CLD})$

Mixed layer model

θ_m, q_m, CO_{2m}

Constant mass divergence

Surface fluxes

$P_{LCL} : RH_m, T_m, q_m, CO_{2m}$

P_{sf} : surface pressure

Vegetation and energy balance models

$RH_{sf}, T_{sf}, q_s(T_{sf}), CO_{2L}$

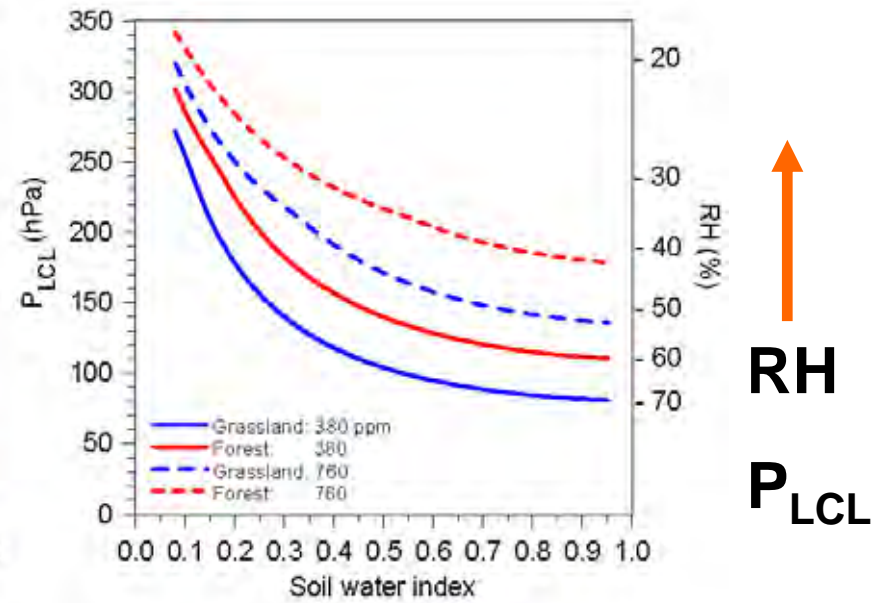
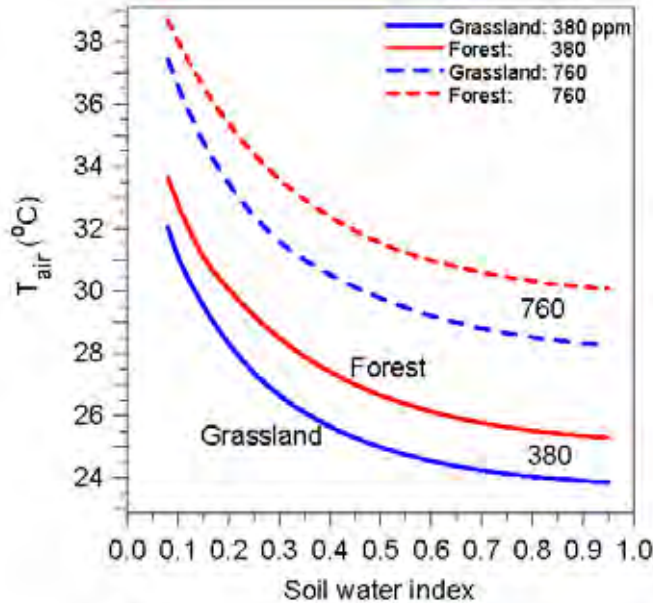
Soil moisture specified

Equilibrium solutions for forest and grassland

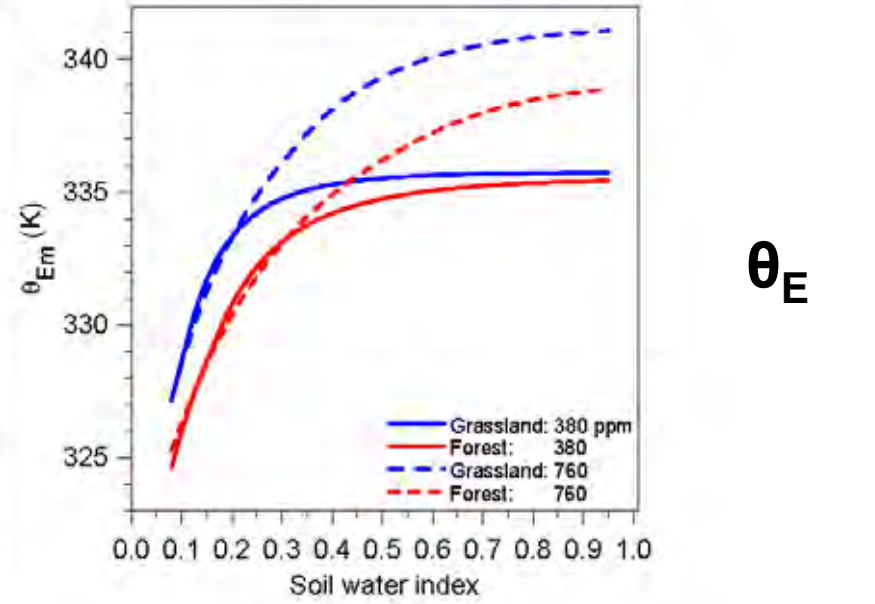
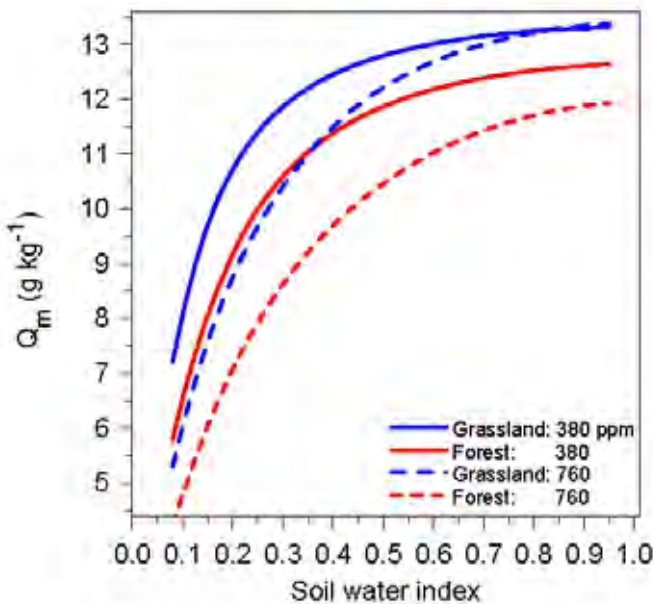
- Current climate: 380 ppm CO₂
- 2100 climate: 760 ppm CO₂
& moist adiabat tropospheric reference T:
tied to SST increase of +2K
[very approx. A1B scenario; WG1, Ch 11]

ML equilibrium

T_{air}



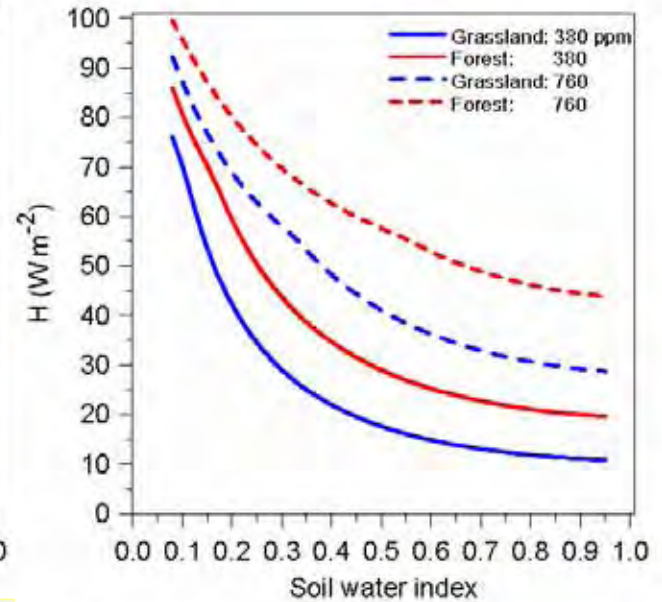
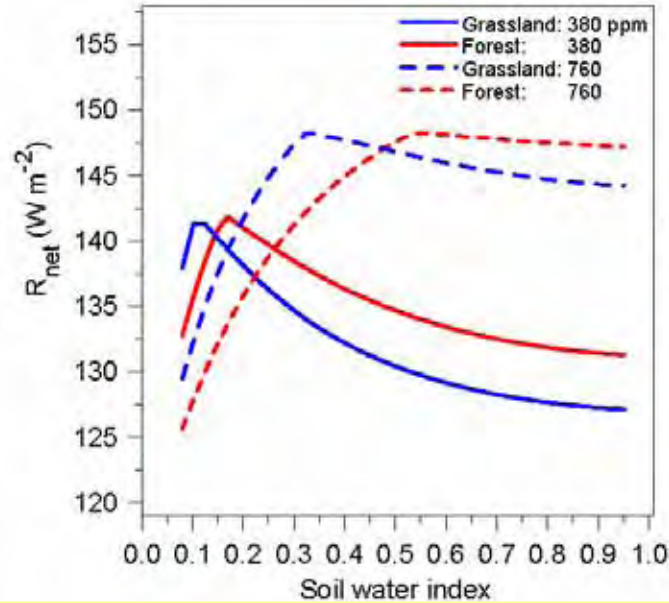
Q



Soil water index

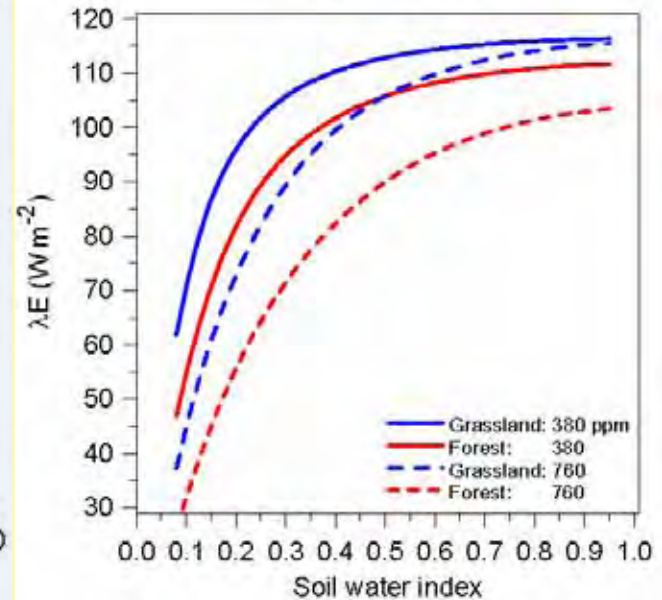
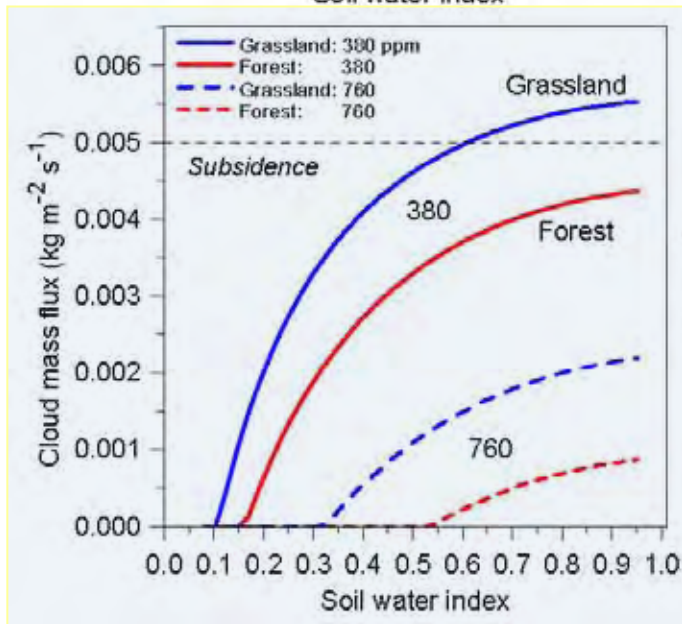
Surface energy fluxes

R_{net}



H

Cloud mass flux

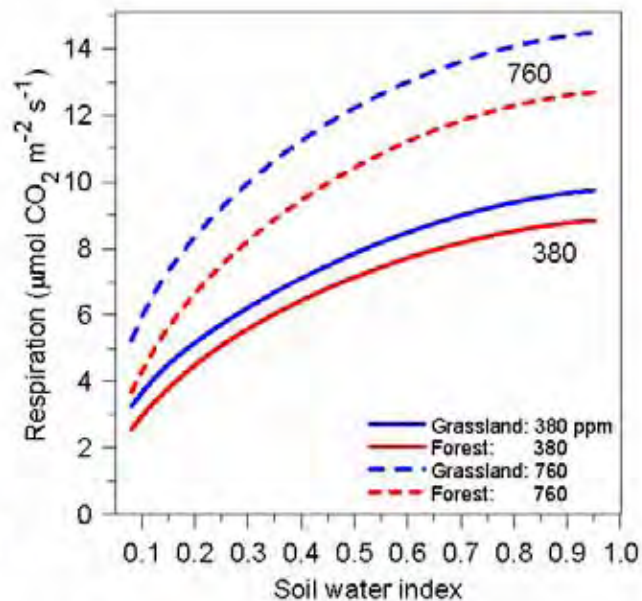
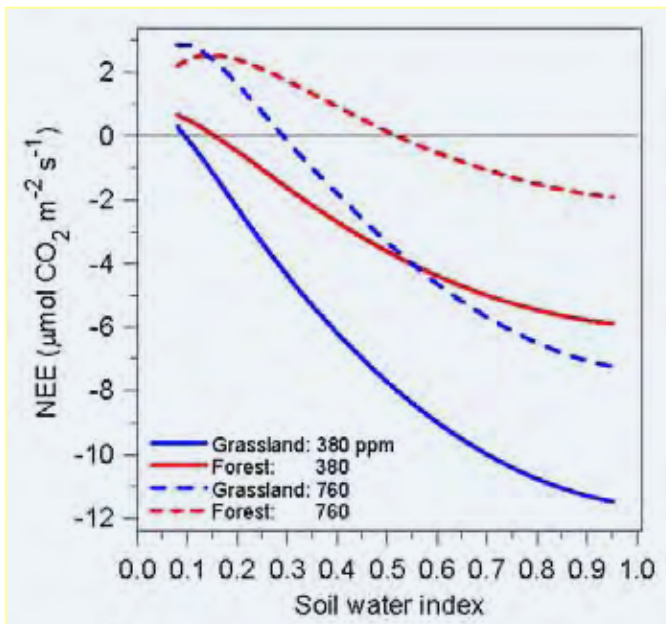


λE

Soil water index

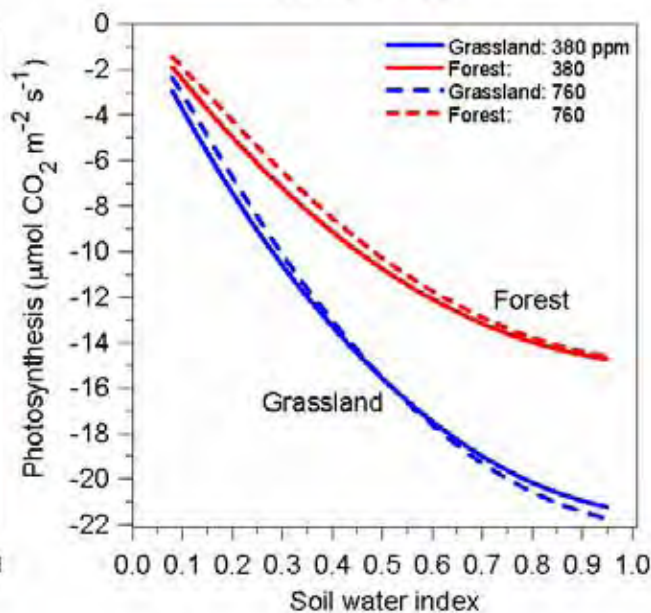
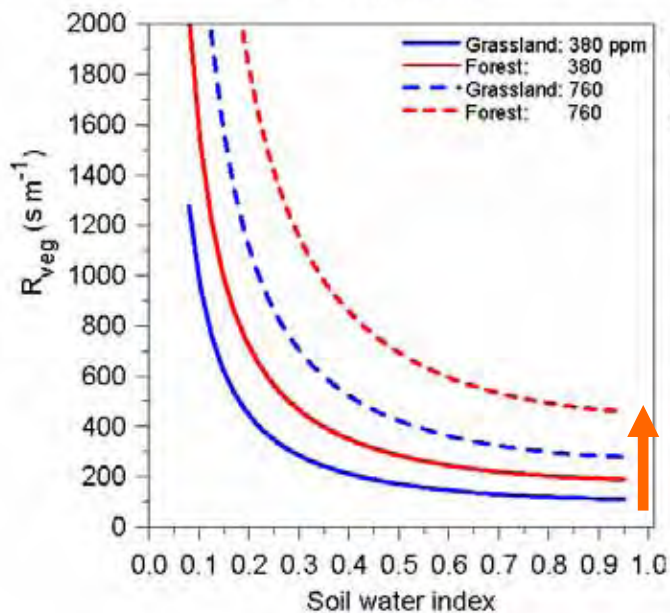
CO₂ fluxes

NEE



Resp

R_{veg}



PH

Soil water index

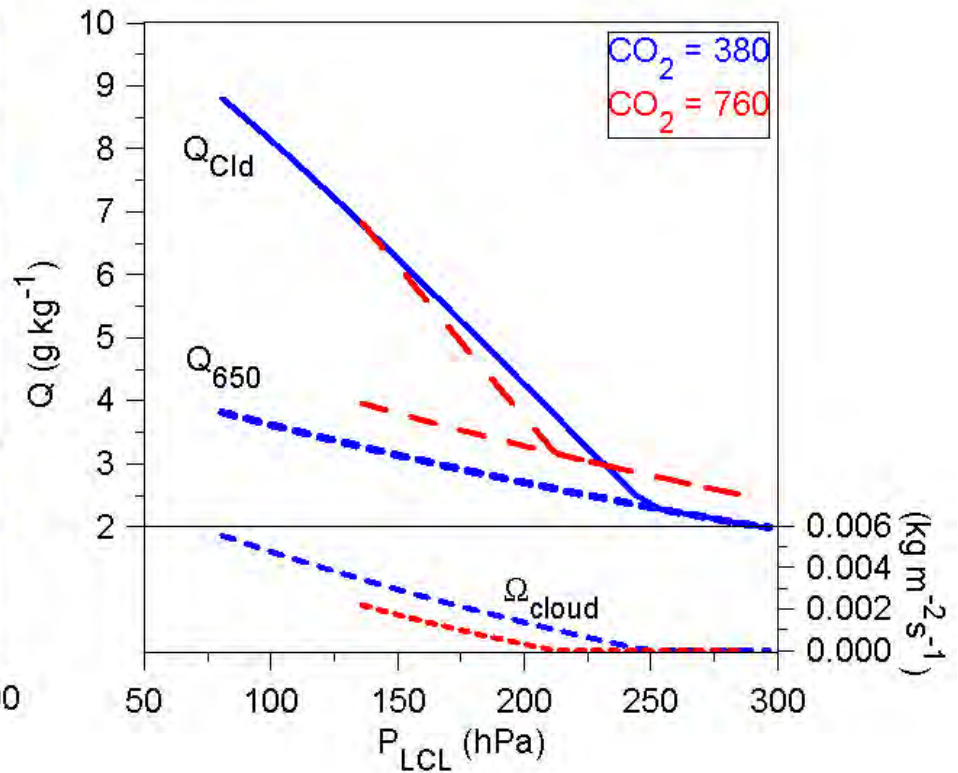
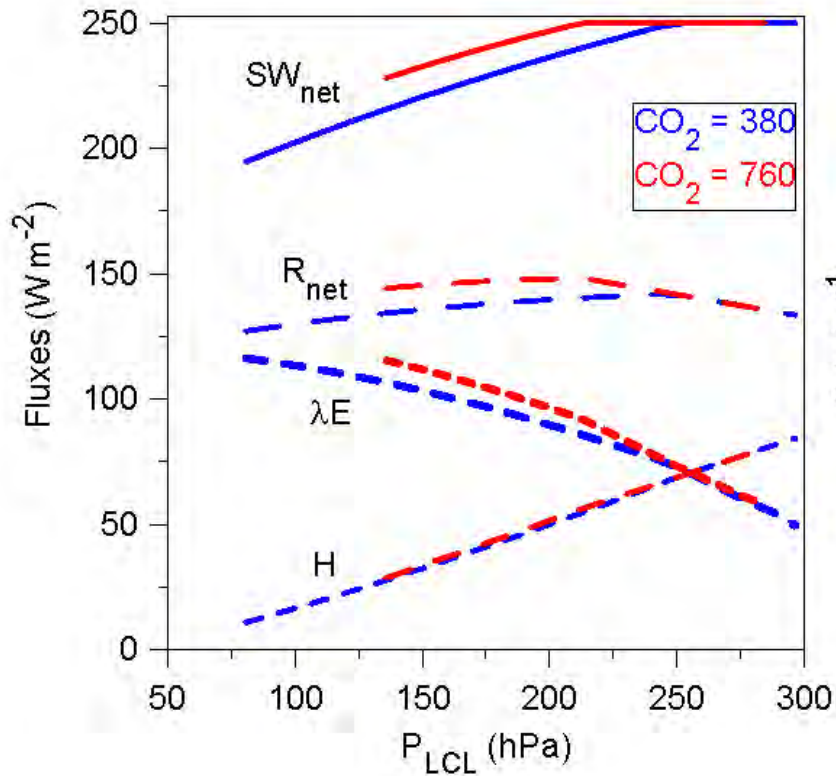
Equilibrium model conclusions

- Mid-lat. forest to grassland conversion **increases**
BL cloud albedo (order +5%)
- Doubling CO₂ **reduces** transpiration, RH and
BL cloud albedo (order -14%)
- This **amplifies surface warming over land**
+2K over ocean to +4.8K [2-m]; +5.6K at land-surface
- Warming with double CO₂ reduces NEE.
[Model forest loses carbon for SWI<0.5]
- If forest to grassland conversion; 2-m land warming
drops to 3K [*Caveats: same soil-water; subsidence*]

Conclusions

- **Simplified model shows large changes in BL-cloud over land with vegetation change and warmer high CO₂ climate**
- **GCM vegetation models should be tested offline in coupled BL mode to separate cloud forcing and carbon sink issues**

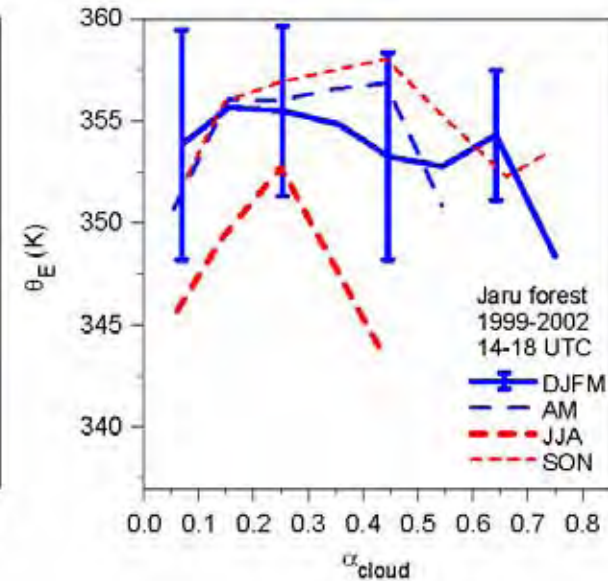
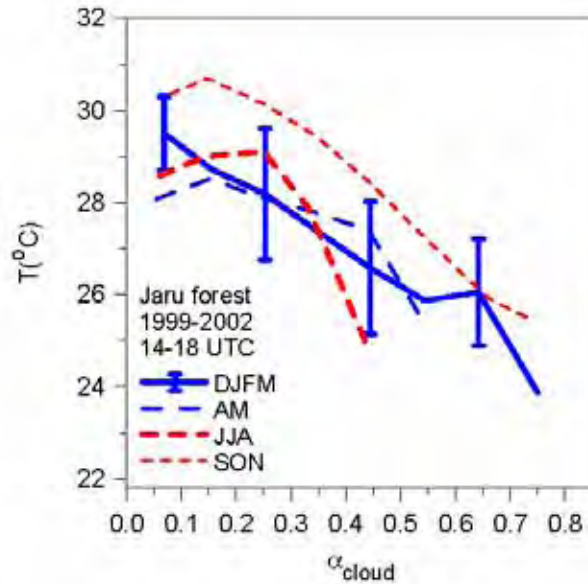
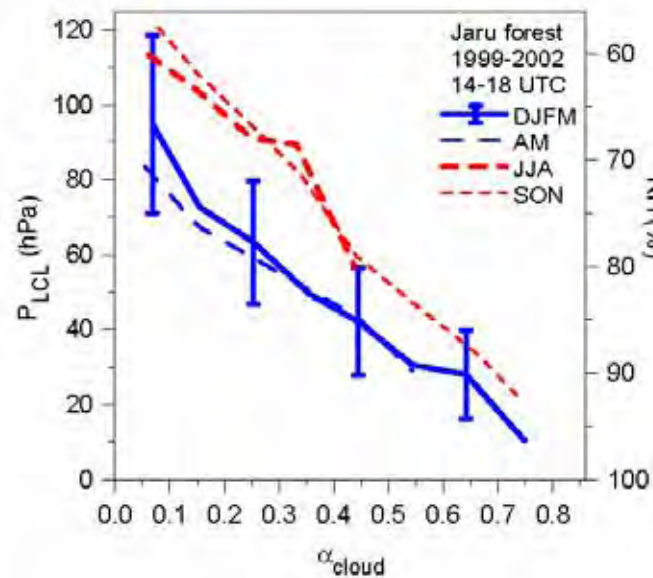
Fluxes, Q & clouds - P_{LCL}



- As cloud $\rightarrow 0$, collapses to ML model
- Only clear-sky LW coupling left

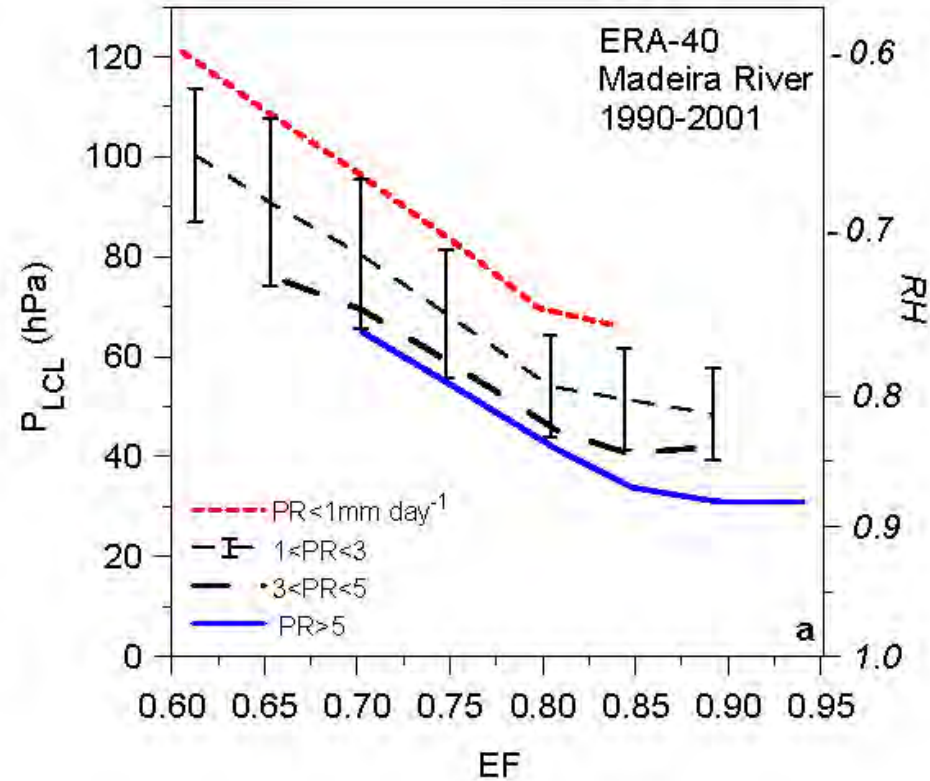
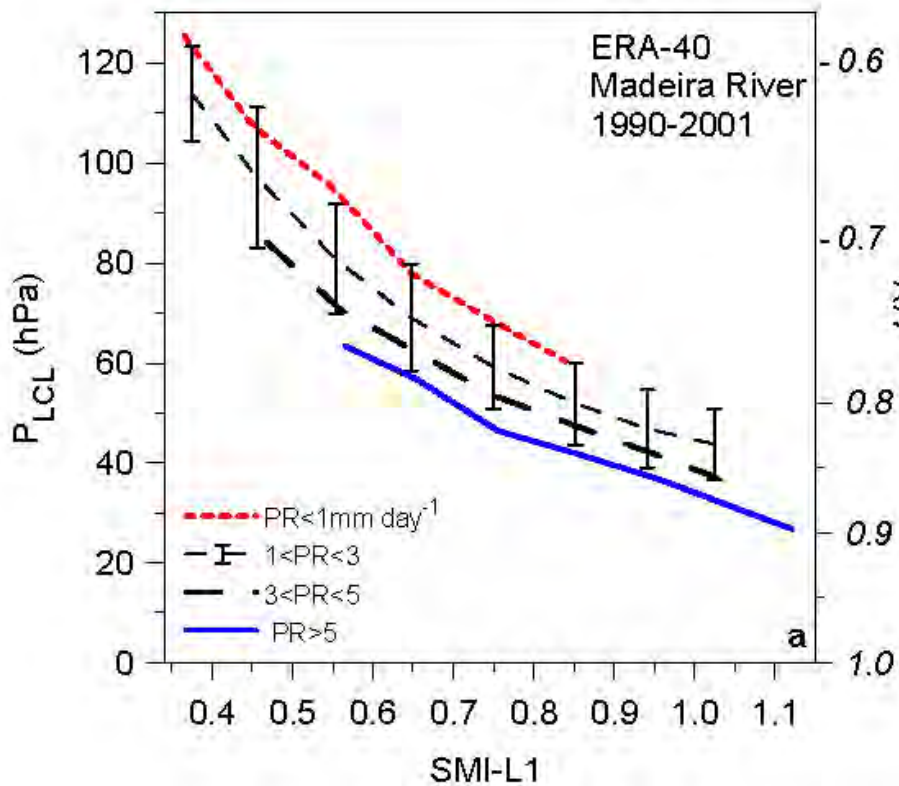
Cloud - BL coupling

Jaru forest – Noon $\pm 2h$



- Cloud amount coupled to cloud-base & RH
- Temperature decreases as cloud increases
- θ_E is flat: regulated by cloud transports

Land-surface-BL Coupling



- $SMI-L1 = (SM - 0.171) / (0.323 - 0.171)$ (*soil moisture index*)
- P_{LCL} stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only P_{LCL} observable: *Mixed layer depth*